IRES²プロジェクト研究

超伝導体が拓く走査プローブ顕微技術の新展開

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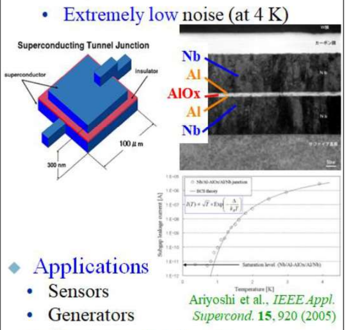
9 産業と技術革新の基盤をつくろう

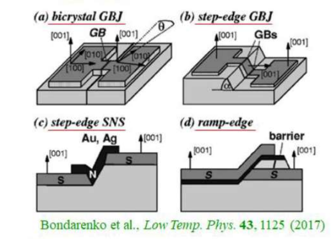
§1 Introduction

Comparison of superconducting tunnel junctions (STJs)

Low Temp. Supercond. (LTS)	High Temp. Supercond. (HTS)
◆ S-I-S junctions are realized. • Extremely low noise (at 4 K)	◆ S-I-S junctions are not realized. • Modest noise (at 77 K)



Ariyoshi et al., *IEEE Appl. Supercond.* 15, 920 (2005)



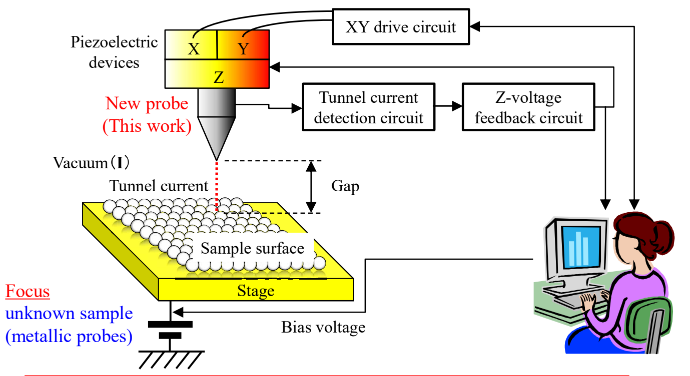
Bondarenko et al., *Low Temp. Phys.* 43, 1125 (2017)

◆ Applications
- Sensors
- Generators
- Quantum computers etc.

◆ Our purpose
- To maximize the potential of HTS electronics by SIS nano-junctions

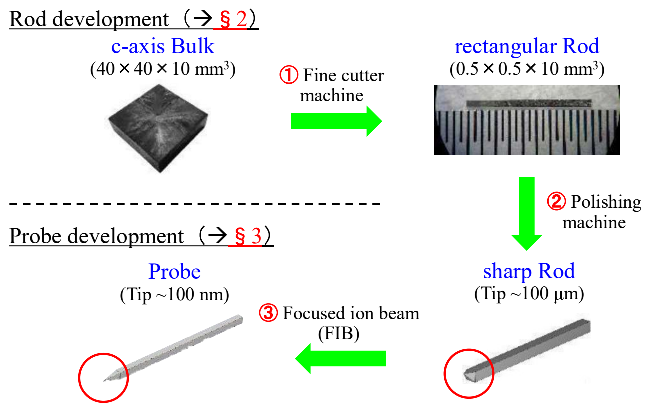
Scanning probe microscope (SPM)

SPM is a term for microscopes based on a scanning tunneling microscope (STM).



An STM equipped with an HTS probe is expected to realize SIS junctions that are separated by a vacuum insulator.

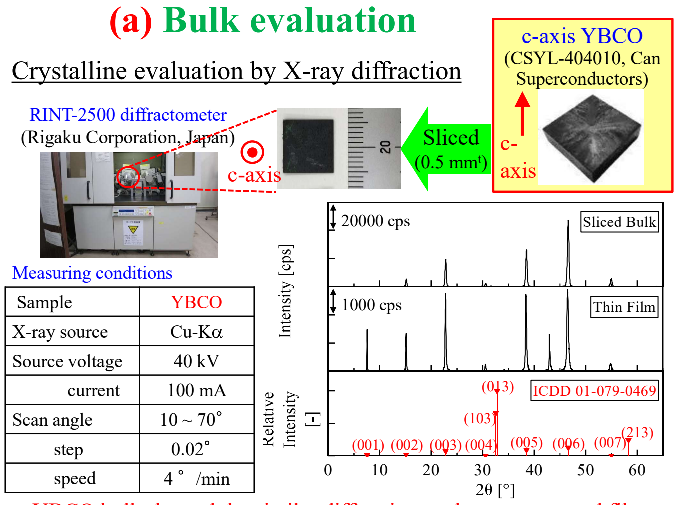
Overview of the fabrication flow



§2 Rod development

(a) Bulk evaluation

Crystalline evaluation by X-ray diffraction

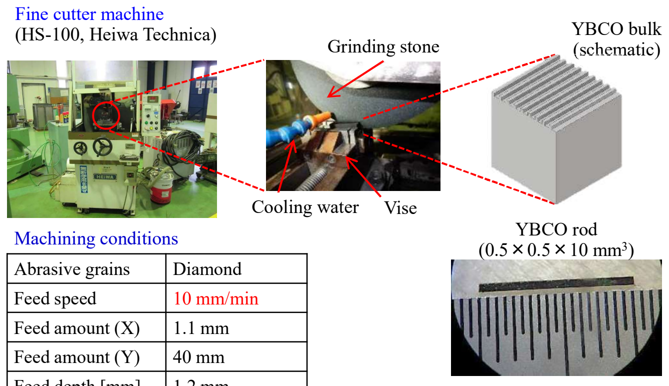


Measuring conditions

Sample	YBCO
X-ray source	Cu-Kα
Source voltage	40 kV
current	100 mA
Scan angle	10 ~ 70°
step	0.02°
speed	4° /min

YBCO bulk showed the similar diffraction peaks to a sputtered film.

(b) Rod fabrication

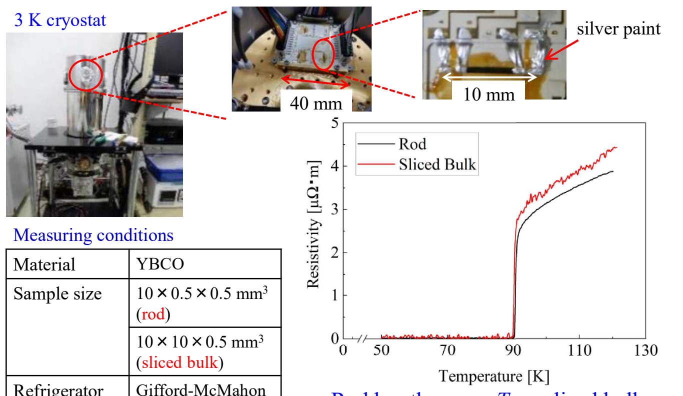


Machining conditions

Abrasive grains	Diamond
Feed speed	10 mm/min
Feed amount (X)	1.1 mm
Feed amount (Y)	40 mm
Feed depth [mm]	1.2 mm
Rotation speed	3,000 rpm

High fabrication yield of >90% without breaking the rod

(c) Rod evaluation



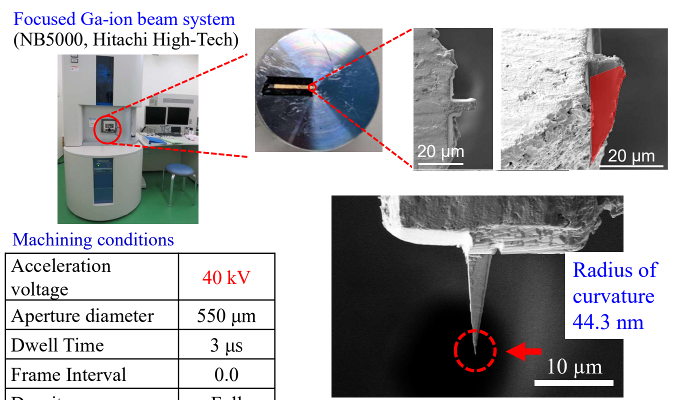
Measuring conditions

Material	YBCO
Sample size	10 × 0.5 × 0.5 mm³ (rod) 10 × 10 × 0.5 mm³ (sliced bulk)
Refrigerator	Gifford-McMahon
Temperature	300 ~ 3 K

Rod has the same T_c as sliced bulk.
→ No damage to superconductivity

§3 Probe development

(a) Probe fabrication



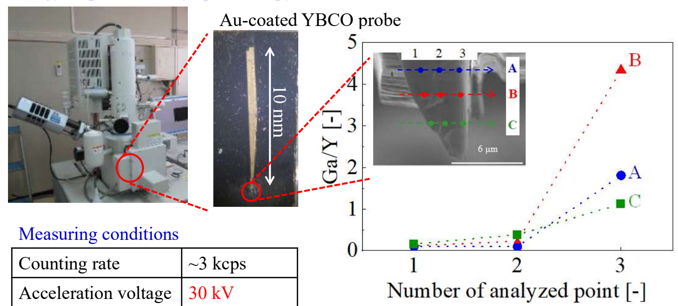
Machining conditions

Acceleration voltage	40 kV
Aperture diameter	550 μm
Dwell Time	3 μs
Frame Interval	0.0
Density	Full
Line Width	1 pixel

Sharp YBCO probe was processed by FIB.

(b) Probe evaluation

Analysis of influence of Ga-ion implantation

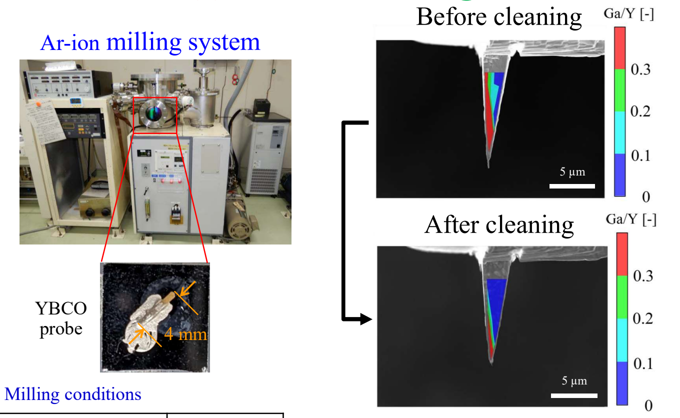


Measuring conditions

Counting rate	~3 kcps
Acceleration voltage	30 kV
Measurement time	100~120 sec
Working distance	15±0.1 mm
Magnification	× 10k

Ga-ion penetration depth < 1 μm
→ The chemical composition was conserved within the rod.

(c) Probe cleaning



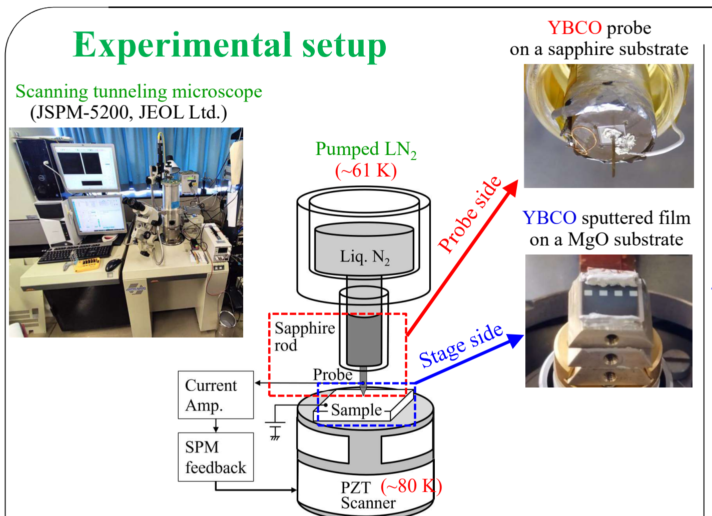
Milling conditions

Acceleration voltage	60 V
Milling time	40 min

→ Production of pure YBCO probes possible by Ar-ion milling.

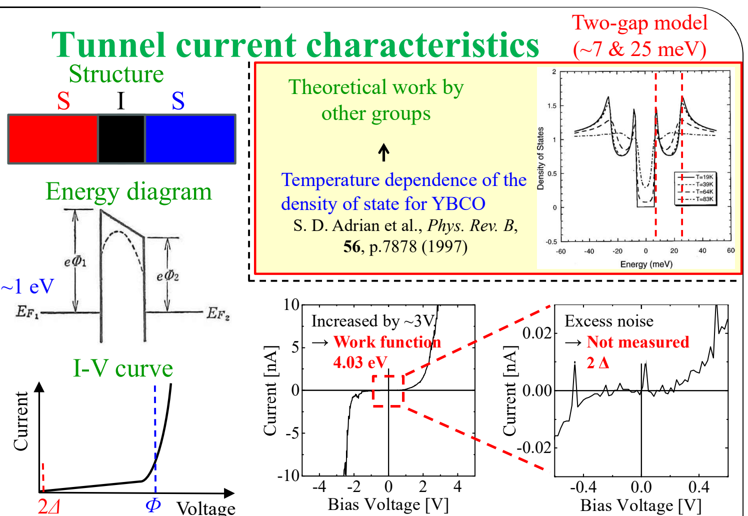
§4 Installation to SPM (STM mode)

Experimental setup



S (YBCO) - I (vac.) - S (YBCO) characteristics was evaluated.

Tunnel current characteristics



Noise reduction and YBCO stage will reveal the SIS nature.

§5 Summary

We proposed, fabricated, and evaluated a YBCO probe for realizing SIS junctions.

■ Rod development
- A c-axis oriented bulk was cut into a rectangular rod using a fine cutter machine.
- T_c of the rod was ~90 K, which was almost the same as that of the original bulk, indicating no critical damage to superconductivity owing to the cutting.

■ Probe development
- One end of the rod was ground to a pyramid shape of ~70 μm radius, and then the apex was further sharpened to 44.3 nm using a focused Ga ion beam.
- The penetration depth of Ga ions from the YBCO surface was <1 μm at 40 kV, suggesting that the chemical composition was conserved inside the rod.

■ Installation to SPM (STM mode)
- A YBCO probe was installed in a LN_2-cooled STM system. Preliminary results about the tunnel current characteristics were obtained. A sharp increase in tunnel current from ~4 V was observed at the high V range, and SIS-like I-V curve was also acquired at the low V range.

• Future works
- Optimization of FIB process → Sharper probe tip, reduced Ga-ion damage
- Atomic force microscope imaging in liquid nitrogen
- Noise reduction in STM → YBCO-based SIS nano-junctions

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技術を究め、技術を創る

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